Macrophyte abundance and distribution in Leschenault Inlet, an estuarine system in south-western Australia

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Abstract

The aquatic flora of Leschenault Inlet is similar to that in other southern estuaries, except that Leschenault Inlet has a relatively high diversity of red algae, and *Hormophysa triquetra* is the dominant brown alga. Total plant biomass was generally 3 000-5 000 t dry weight, with a maximum in spring. There were large differences in the biomass of seagrass and macroalgae between individual surveys, but in general seagrass biomass and total macroalgal biomass appear relatively stable in the long term. Total plant biomass per unit area in Leschenault Inlet was similar to that in the Peel-Harvey estuarine system. The major difference was the relative proportions of total biomass accounted for by seagrass, brown algae and green algae. Macrophyte biomass in Peel-Harvey is dominated by green algae, whereas in Leschenault Inlet seagrass and brown algae are dominant. The inlet appears to have been in an acceptable state under the nutrient loading regime and hydrodynamic conditions of the years when the surveys were carried out.

Keywords: Leschenault Inlet, south-western Australia, estuary, aquatic vegetation, macrophytes, *Halophila ovalis*, *Hormophysa triquetra*, macrophyte biomass

Introduction

Leschenault Inlet is the largest (*ca* 27 km^2) inland waterway in the Bunbury region, and of considerable importance for recreation, fishing (commercial and amateur) and conservation. It is a long, shallow (up to 2 m deep) coastal lagoon in an interdunal depression, with shallow platforms of sand and muddy sand along the eastern side, and deep mud on the western side.

The inlet is connected to the ocean by an artificial channel ('The Cut', Fig 1), and both the Collie and Preston Rivers discharge into the inlet west and south, opposite the Cut. The construction of Wellington Dam on the Collie River has significantly reduced the volume of fresh water entering the inlet (Anon 1983) and salinities in the inlet are essentially marine for most of the year, although the northern end (north of Waterloo Head, Fig 1) becomes hypersaline in summer. Until recently the inlet was traversed by a wastewater pipeline (SCM Chemicals Ltd), carried across the estuary for part of the way by a 900 m length of rock causeway, and across the remainder by a trestle bridge. Between July and December 1992 the trestle bridge was completely removed, and a 100 m section of the (eastern) shore end of the causeway plus two smaller sections (total length 13 m), were replaced by trestle walk-ways.

The inlet is subject to the impacts of residential, industrial, agricultural and port development, and considerable recreational use. At present it is in a relatively acceptable condition, but nutrient input due to runoff from agricultural land in the catchment has the potential to create algal problems similar to those experienced in the Peel-Harvey estuarine system (Lavery *et al.* 1995). Like the Peel-Harvey, the catchment of Leschenault Inlet is largely comprised of nutrient-poor sandy soils, and there are significant ferti-

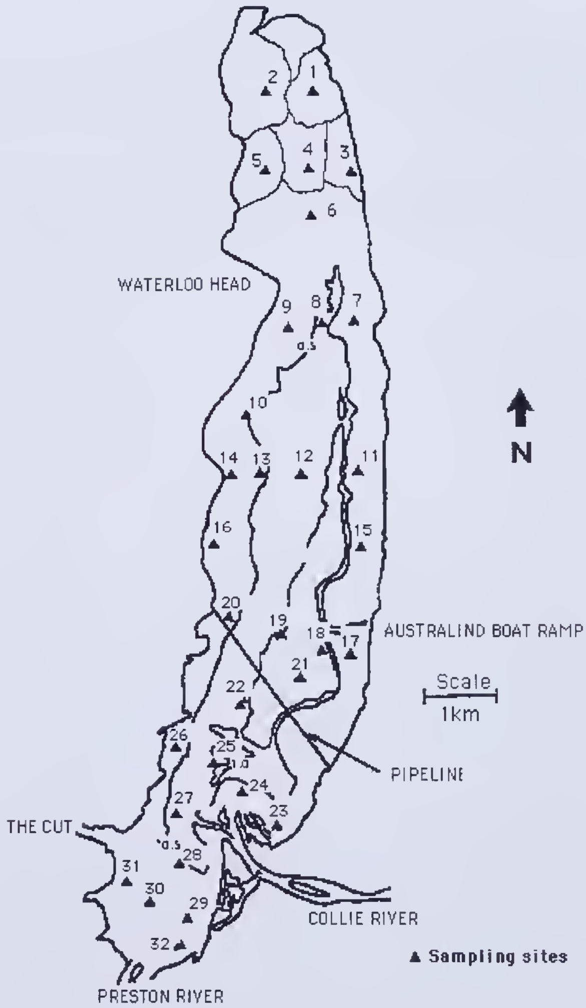

Figure 1. Leschenault Inlet, showing 0.5 and 1.0 m depth contours and sampling sites for macrophyte biomass.

Table 1. Aquatic angiosperms and macroalgae observed in Leschenault Inlet and their presence (+) or absence (-) in other south-western Australian estuaries.

	Leschenault Inlet	Peel-Harvey[1] Estuaries	Wilson[2] Inlet	Oyster[3] Harbour
AQUATIC ANGIOSPERMS				
Halophila ovalis	+	+	-	+
Ruppia megacarpa	+	+	+	-
Heterozostera sp	+	-	-	+
Zostera muelleri	+	+	-	-
MACROALGAE				
CHLOROPHYTA				
Chaetomorpha linum	+	+	+	+
Lamprothamnium papulosum	+	+	+	-
Enteromorpha sp	+	+	+	+
Cladophora sp	+	+	+	-
Caulerpa sp	+	+	-	+
PHAEOPHYTA				
Hormophysa triquetra	+	-	-	-
Dictyota paniculata	+	-	+	+
RHODOPHYTA				
Gracilaria sp	+	+	+	+
Chondria sp	+	+	+	+
Laurencia sp	+	+	-	+
Spyridia filamentosa	+	-	-	+
Ceramium sp	+	*	+	+
Hypnea episcopalis	+	-	-	-

1 Lukatelich (unpublished) (BP Refinery, Kwinana)
2 Lukatelich *et al.*(1984)
3 Bastyan (unpublished observations; School of Environmental Science, Murdoch University, Perth)

Table 2. The mean areal biomass in g dry wt m^{-2} for SYMAP estimates of macrophytes for Leschenault Inlet and Peel Inlet over the sampling period November 1984 to April 1993. Standard errors are generally 15-40 % of the mean.

Date	Leschenault Inlet			Peel Inlet		
	Seagrass	Macroalgae	Total macrophytes	Seagrass	Macroalgae	Total macrophytes
Nov 1984	44.7	136.0	180.7	23.8	155.8	179.6
Apr 1985	37.0	92.6	129.6	2.3	222.0	224.3
Aug 1985	21.3	46.4	67.7	5.6	207.1	212.7
Nov 1985	14.0	94.3	108.3	16.7	45.2	61.9
Oct 1987	40.7	149.9	190.6	18.2	193.4	211.6
Feb 1988	61.7	77.8	139.5	19.6	92.7	112.3
May 1988	76.2	46.8	123.0	20.2	114.3	134.5
Nov 1988	61.1	93.8	154.9	19.9	25.0	44.9
May 1989	48.8	101.2	150.0	15.5	111.5	127.0
Nov 1989	51.8	101.7	153.5	24.6	116.6	141.2
May 1990	72.1	140.3	212.4	17.5	73.4	90.9
Oct 1990	49.1	209.0	258.1	54.7	176.6	231.3
May 1991	67.9	55.7	123.6	60.1	72.2	132.3
Nov 1991	33.8	84.3	118.1	-	-	-
Mar 1992	54.1	53.5	107.6	31.7	131.7	163.4
Apr 1993	42.2	50.0	92.2	23.2	237.7	260.9

lizer inflows from agricultural areas. Leschenault Inlet receives almost the same level of nutrients as the Peel-Harvey, but lacks the associated problems of algal blooms due to a combination of effective tidal exchange and the fact that the Collie and Preston Rivers enter the inlet opposite the Cut, which ensures rapid loss of river-borne nutrients to the ocean (Anon 1990).

The present paper summarises material from a number of surveys that document seasonal and long-term variation in the spatial distribution and biomass of aquatic macrophytes in the Inlet. It incorporates data from earlier reports (Lukatelich 1985; Lukatelich 1989) and presents new data for autumn 1988 to autumn 1993. Estimates have been made of total plant biomass and individual species biomass for the dominant macrophytes, and their distributions have been mapped. Data are compared with information from other southwestern Australian estuaries.

Materials and Methods

Seasonal surveys were carried out between November 1984 and November 1985; and October 1987 and May 1988. Biannual surveys (spring and autumn) were conducted between autumn 1988 and autumn 1992, followed by one survey in autumn 1993.

Stratified macrophyte sampling was carried out at 32 sites (Fig 1) selected to best represent the environments in the Inlet. Sites were spaced at relatively regular intervals along the length of the Inlet, but across the width were selected to reflect depth intervals; fewer sites were sampled in the central basin. At each site, five replicate cores were collected by divers using Perspex corers (9 cm diameter, 50 cm long, area 64 cm^2), which were pushed into the sediment surface over the benthic macrophytes and sealed. Plant material was sieved to remove excess sediment, sorted into species categories and oven dried (70 °C) to constant weight. Dry weights were determined to two significant figures and species biomass expressed as weight per unit area. Estimates for biomass are means of five replicates. Total macrophyte biomass for an individual site was 0 to 1 000 g dry wt m^{-2}. Standard errors for the replicates from particular sites were 15-40% of the mean, the relatively high variation being accounted for by the patchy distribution of the macrophytes, though where macrophytes occurred, the cover was usually quite continuous. High variability was offset to some extent by the smoothing effect of a computer-generated mapping programme (SYMAP, Dougenik & Sheehan, 1977), which accepted data from plotted, individual sites and drew up contours of different quantities of biomass. The weights bounded by contour intervals were summed to estimate total biomass for the inlet. Before May 1989, maps were manually digitised: these were re-analyzed using SYMAP. A comparison of the manual and computer digitisation for this period revealed errors of ± 5-10 %. This is considered acceptable, but biomass data presented here for before May 1989 will differ slightly from those presented in earlier reports.

The method for estimating biomass for the entire inlet is subject to the limitations of the SYMAP method, and there were relatively few sites sampled for such a large water body, which may lead to overestimates of biomass in most cases. Nevertheless it is considered that adherence to the same sampling sites and methods over the sampling period has produced a valid representation of distribution patterns and trends over the periods investigated.

Results and Discussion

Aquatic flora

A list of species from Lukatelich (1989) is reproduced in Table 1. No further species were observed in the present study, though the list of red algae is incomplete, as there are taxonomic problems with some species. The seagrasses *Amphibolis antarctica* and *Posidonia australis* have been re-

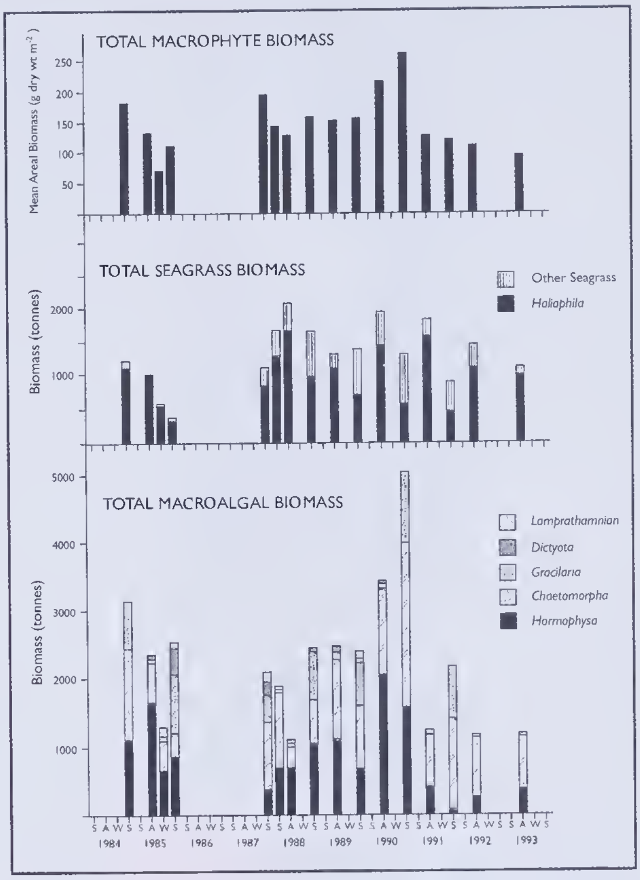

Figure 2. A: Mean areal macrophyte biomass and total biomass in Leschenault Inlet, 1984-93, in summer (S), in autumn (A), in winter (W), and in spring (S) respectively. **B:** Total seagrass biomass in Leschenault Inlet, 1984-93, in summer (S), in autumn (A), in winter (W), and in summer (S) respectively. **C:** Total biomass of major macroalgal species (tonnes) in Leschenault Inlet , 1984-93, in summer (S), in autumn (A), in winter (W), and in summer (S) respectively.

corded by Anon (1983) as drift material in Vittoria Bay and around the channel entrance, but they do not appear to grow in the Inlet.

Total macrophyte biomass

Total biomass for the estuary (3 000-5 000 t dry weight) was similar on all occasions except August 1985 (1 800 t dry weight), and May and October 1990 (5 700-7 000 t dry weight respectively). Table 2 includes a breakdown into species. The value for August 1985 represents the only winter data, and low macrophyte biomass would be expected, as growth of seagrasses and macroalgae would be lowest under winter conditions of low light and temperature (Hillman *et al.* 1995; Lavery *et al.* 1995).

The high estimates (Fig 2) of macrophyte biomass per unit area in spring and autumn of 1990 are more difficult to interpret. There are few physico-chemical data for the Inlet over this period, and little evidence from rainfall data or estimates of catchment flow (Donahue & Deeley 1994) that either nutrient inputs were unusually high providing more nutrients for macrophyte growth; or that inflow was unusually low, which might have resulted in improved water clarity and more light for macrophyte

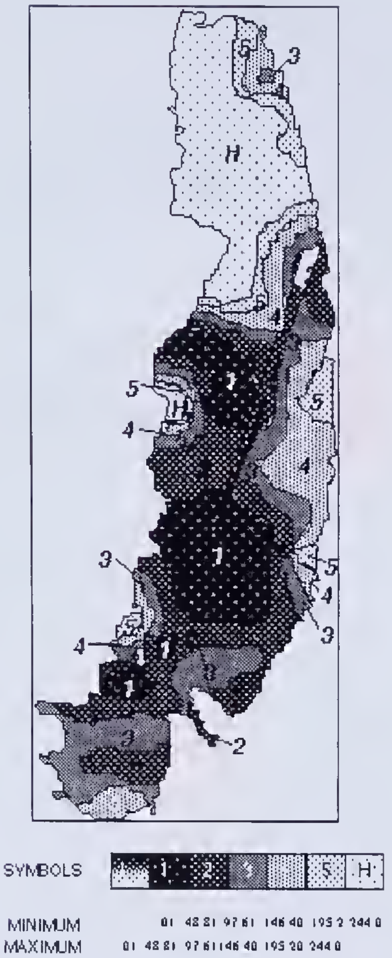

Figure 4. Total macrophyte biomass for Leschenault Inlet in October 1987. Values are g dry wt m^{-2}.

Figure 5. Total macrophyte biomass for Leschenault Inlet in November 1989. Values are g dry wt m^{-2}.

growth. It is likely that reduced wind stirring increased water clarity (see further discussion below) during the main macrophyte growing period (spring to autumn), but there are no data to confirm this. Given that errors for biomass estimates within a particular site were high, it is likely that apparent inconsistencies in biomass estimates for the 1990 periods (as well as spring 1984 and 1987) may well result from statistical variation.

Seasonal variation of particular macrophytes

It is possible to discern seasonal patterns for each type of macrophyte, despite the limited data set.

Seagrass. The biomass of seagrass, dominated by the species *Halophila ovalis* (Fig 2B, see Table 1 for other seagrass species present), varied from 378 t (November 1985) to 2 059 t (May 1989). The seasonal pattern of maximum biomass in late summer/early autumn and a minimum in late winter/early spring for this seagrass is similar to those reported for *Halophila* in other southwestern Australian estuaries (Hillman *et al.* 1995).

Macroalgae. Total macroalgal biomass varied from 1 261 t (May 1988) to 5 643 t (October 1990). Seasonal patterns differed for each of the algal classes comprising total macroalgal biomass. The seasonal maximum was typically reached in spring (Fig 2C), unlike the Peel-Harvey estuarine system which typically reached maximum biomass in late summer/early autumn (Lavery *et al.*1995). Red algal biomass varied from 115 t (August 1985) to 2 264 t (October 1987), with a prominent peak in spring. Spring values were 880-2 300 t, for other seasons from 100-360 t. Seasonal patterns were less clearly defined for brown and green algae. Brown algal biomass was 46 t (November 1991) to 2 069 t (May 1990). There was a general trend within each year for the seasonal maxima to be attained in autumn. Green algal biomass was 374 t (May 1988) to 2 539 t (October 1990), with no clear pattern in maximum biomass attained each year.

Comparison between Leschenault Inlet and Peel-Harvey

Total biomass. It is useful to compare estimates of total plant biomass for Leschenault Inlet with data from the Peel-Harvey. Because of the large difference in the areas of Leschenault Inlet (27 km^2) and the Peel-Harvey (total area 133 km^2; 'Peel' 84 km^2, 'Harvey' 49 km^2) the comparison must be made on an areal basis. Mean areal biomass estimates for Peel Inlet (Lavery *et al.* 1995) for the same sampling dates as Leschenault Inlet ranged from 62 to 261 g dry wt m^{-2}, with an average of 161 g dry wt m^{-2}. Mean areal biomass in Leschenault Inlet ranged from 68 to 258 g dry wt m^{-2}. (Table 3), with an average of 144 g dry wt m^{-2}. On the basis of these data, it appears that total plant biomass

Figure 6. Total *Halophila ovalis* biomass for Leschenault Inlet in November 1991. Values are g dry wt m^{-2}.

Figure 7. Total *Chaetomorpha linum* biomass for Leschenault Inlet in November 1991, mapped. Values are g dry wt m^{-2}.

per unit area is similar in the Peel-Harvey and Leschenault systems.

Biomass composition. The major difference between Leschenault Inlet and the Peel-Harvey is in the composition of the biomass. This can be summarised as follows:

1. Seagrasses accounted for > 30% of total biomass (range 12-62%) in Leschenault Inlet, whereas they account for < 15% of total biomass in the Peel-Harvey (Table 3).
2. Green algae comprised 11-43% of total plant biomass in Leschenault Inlet, whereas in the Peel-Harvey they accounted for > 85% of total macrophyte biomass.
3. Brown algae accounted for 14-49% of total macrophyte biomass in Leschenault Inlet. In contrast, in the Peel-Harvey brown algae accounted for < 0.5% of total biomass. Maximum mean areal biomass of brown algae in the Peel-Harvey is 3.7 g dry wt m^{-2}, compared with 76.6 g dry wt m^{-2} in Leschenault Inlet.
4. Red algae comprised a significant proportion (20-30%) of total biomass in Leschenault Inlet each spring, but not at other times of year (less than 10% of total biomass). In Peel Inlet red algae seldom comprised more than 10% of total macrophyte biomass at any time.

A large proportion of total macrophyte biomass in Leschenault Inlet is accounted for by seagrasses. This suggests that the overall water quality and clarity in Leschenault Inlet is better than in some other estuaries. Normally in estuaries and enclosed marine embayments with high nutrient loads, macrophytes are dominated by green algae (*e.g.* Sawyer 1965; Steffensen 1974; Buttermore 1977; Lowthion *et al.* 1985; McComb & Lukatelich 1995; Lavery *et al.* 1991).

Plant distribution and biomass

A comparison of the SYMAP distribution patterns, examples of which are given in Fig 3 to 7, indicates that on all occasions the highest plant biomass was in the northern section of the Inlet. Distribution patterns for total plant biomass appear to have changed very little (although total biomass has varied between years) since macrophyte monitoring commenced in 1984. The northern section (north of Waterloo Head, Fig 1) is very shallow (< 0.5 m) and exchange with the ocean is restricted because of its distance from the Cut, as shown by the large difference in salinities between the lower portion of the inlet and this section. The southern section of the inlet is essentially marine and was dominated by the seagrass *Halophila ovalis*. In the northern section plant biomass was dominated by the brown alga *Hormophysa triquetra*, the green alga *Chaetomorpha linum*, and the charophyte *Lamprothamnium papulosum*.

Figure 8. Total macrophyte biomass for Leschenault Inlet in November 1984. Values are g dry wt m^{-2}.

As with total plant biomass, distribution patterns for individual types of macrophytes have changed little since monitoring commenced. The distribution maps depicted in Lukatelich 1989) remain valid, and have not been repeated here.

Seagrasses. *Halophila ovalis* is widely distributed in Leschenault Inlet, and is only absent from a small area of deep water in the centre of the inlet (Fig 6). Leschenault Inlet lies parallel to the prevailing southwesterly winds, and the fine, muddy sediments are easily resuspended by wind-induced mixing. This results in high turbidity, which is probably the reason for the absence of *Halophila* in the deepest sections of the inlet. Maximum areal biomass of *Halophila* was generally found just south of Waterloo Head on the sandy marginal platforms of the eastern side of the inlet. The high biomass of *Halophila* in autumn 1988), 1990 and 1991 compared to autumn 1985 may have been due to improved light penetration. *Halophila* biomass at some of the deeper sites (*e.g.* 18, 19, 22 and 25; Fig 1) was much higher in May 1988, 1990 and 1991 (see also Table 2).

Ruppia megacarpa and *Heterozostera tasmanica*, seagrasses which contribute to total seagrass biomass, were largely confined to shallower sections of the sandy marginal platform on the east of the inlet. *Zostera muelleri* was found in the inlet, but only near the entrance channel to the ocean.

Green algae. The dominant green alga in Leschenault Inlet was *Chaetomorpha linum*, which was largely confined to the northern section (Fig 7). The biomass of *Chaetomorpha* was from 298 t (May 1988) to 2 400 t (October 1990). The maximum areal biomass of this species was 705 g dry wt m^{-2} in 1990 at site 9.

The Charophyte *Lamprothamnium papulosum* was restricted to the northern section of the inlet, and attained a maximum biomass of 133 t in October 1987.

Brown algae. *Hormophysa triquetra* , the dominant brown alga, was widely distributed in the northern section of the inlet and also occurred along the eastern side as far south as the entrance to the Collie River. It had a maximum biomass of 2 030 t (May 1990) compared to 402 t (November 1985) for *Dictyota*. *Dictyota paniculata*, a small unattached brown alga, occurred on the eastern side of the inlet between Waterloo Head and the entrance to the Collie River. The maximum areal biomass error recorded for *Hormophysa* over the sampling period was 567 g dry wt m^{-2} in 1985 at site 2 (Table 2).

Red algae. Red algae were widespread, with a general distribution similar to that of *Halophila ovalis*. Some of the reds, in fact, occur as epiphytes on *Halophila*. The dominant red genus was *Gracilaria* and its spring biomass (the seasonal maximum) ranged from 405 t (1987) to 991 t (1990). Maximum areal biomass of *Gracilaria* was 350 g dry wt m^{-2} in 1991 at site 23 (Table 2).

Plant tissue nutrient content

There are limited data for concentrations of nitrogen and phosphorus in the tissues of macrophytes from Leschenault Inlet. Values for Ruppia and Halophila were similar, with nitrogen concentrations of 7.5-27.6 mg g^{-1} dry weight and phosphorus concentrations about one tenth of this, at 0.6-5.0 mg g^{-1} dry weight. These are within the range reported for other seagrasses (Hillman *et al.* 1995).

Tissue concentrations of the green alga *Chaetomorpha linum* were 10.1-38.8 mg N g^{-1} dry weight and 0.18-1.88 mg P g^{-1} dry weight. Such data can be most readily interpreted if they can be compared with a 'critical tissue nutrient concentration' (the concentration below which growth is limited by the nutrient concentration). If the critical concentrations determined for *Chaetomorpha linum* in Peel Inlet by Lavery *et al.* (1991) are applied, then growth of this species in Leschenault Inlet is never nitrogen limited, and only occasionally phosphorus limited, near the northern end of the inlet. These limited data imply that nutrients may not be limiting to algal growth in the Inlet. If growth is not limited by nutrient availability, an alternative hypothesis is that water clarity may be more important, at least at times, in determining macroalgal biomass, as found for the Peel-Harvey system (Birch *et al.* 1981; Gordon & McComb 1989; Lavery *et al.* 1991, 1995).

Macroalgal biomass was unusually high in spring 1990, but this did not coincide with high estimated nutrient input to the inlet (Donahue & Deeley 1994), consistent with the view that algal biomass may not be nutrient-limited.

Most seagrass and algal species found in Leschenault Inlet also occur in the Peel-Harvey, Wilson Inlet and Oyster Harbour. The well flushed and essentially marine nature of the southern section of Leschenault Inlet has resulted in a relatively low macrophyte biomass that is dominated by seagrasses. The northern section of the inlet appears poorly flushed, and has a relatively high plant biomass dominated by brown and green algae. Rooted (*Halophila* sp) and attached (*Hormophysa* sp) macrophytes dominate plant biomass, and the proliferation of free floating green algae that causes beach fouling problems in the Peel-Harvey System has not occurred. The brown alga *Hormophysa triquetra*, prominent in Leschenault, also occurs in the Swan/Canning (Allender & Smith 1978; Allender 1981) and Blackwood River estuaries; in the latter a low macroalgal species diversity compared to the Swan is attributed to the shortness of the marine phase in the Blackwood compared to the Swan, and paucity of firm substrate (Congdon & McComb 1981). Biogeographically the southwestern Australian coast has a particularly high diversity of red algae (Womersley 1981), and the largely marine nature of the southern half of Leschenault Inlet compared to estuaries which experience greater extremes of salinity, may favour the survival of these algae.

As noted above, water clarity may be a more important than nutrients in controlling plant biomass, but the data are limited. It should also be emphasised that nutrient inputs from the Parkfield Drain (which are not well documented) could be more critical than total nutrient input to the inlet. Tidal exchange and the silting of rivers probably result in a degree of 'buffering' against effects of nutrient inputs from the associated catchments, but as the magnitude of such buffering is unknown, nutrient inputs should be minimised, whilst any increase in nutrient loading to the northern section of the inlet, which is less well flushed, has the potential to result in the proliferation of nuisance green algae.

Despite high biomass in the northern section, the inlet appears to have been in an acceptable state under the nutrient loading regime and hydrodynamic conditions of the years when the surveys were carried out.

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